An Ecological Survey of Whitewater Gorge.

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At Richmond, Indiana, the east branch of Whitewater River runs through a narrow rock gorge for a distance of about three miles. This miniature canyon is commonly called the Whitewater gorge. It varies in

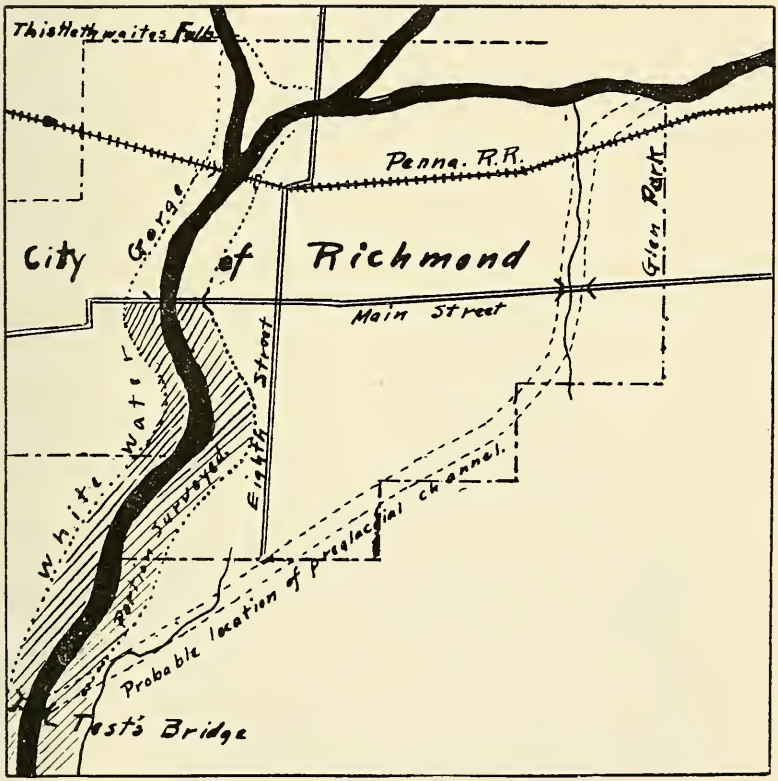

Fig. 1.

depth from 60 ft. to 120 ft. and in width from 200 ft. to 800 ft. on the floor. The gorge terminates rather abruptly at Test's Mills, about two

miles below Main street, Richmond, and from that point to its mouth the valley is generally broad.

This gorge was formed as a direct result of the glacial phenomena of the region. There is evidence that at the close of the Early Wisconsin ice sheet period, the river occupied a channel much to the eastward of its present course. Wells to the south of Glen Park, nearly three miles east of the present river channel indicate at that point an old channel now filled with drift. The streams in Glen Park seem to occupy this same old channel. From this and other evidence it seems probable that this old channel passes to the east of the city of Richmond, and connects with the present river valley somewhere below Test's Mills.

The advance of the Late Wisconsin ice sheet resulted in filling up this old channel with drift. There is evidence that this ice advance was from two directions, north-west and north-east, and that the terminal moraines of the two lobes did not come together. The river, forced out of its old channel, took up a new course between the two moraines. With the melting of the ice sheet, the volume of water discharged by the stream would be very large, and erosion of its channel correspondingly rapid. Since the retreat of the ice, it has carved the present gorge.

The rock of the gorge is Hudson River or Cincinnati limestone. This is a favorite collecting ground for paleontologists interested in this particular portion of the Lower Silurian beds. Trilobites are not numerous, though several species are found. Calymene senaria is commonest. Rynchotrema capax, Zygospira modesta, Platystrophia biforata and Leptæna rhomboidalis are the characteristic brachiopods. Streptolasma is extremely common.

The character of the rock is of extreme importance in the consideration of the ecology of the region. The rock is soft and very thin-bedded, and is rendered still more unstable by the alternation of thin beds of shale of a soft calcareous nature with the layers of limestone. The limestone itself is shaly and weathers very rapidly. Three inches is probably the average thickness of the rock layers. The amount of shale varies greatly, even within limited areas. In general, the shale makes up about one third of the total rock.

As a result of the nature of the rock, steep cliffs are maintained only where active erosion of the base is going on. As soon as river erosion ceases, the slope becomes gentler at once. There is a considerable amount

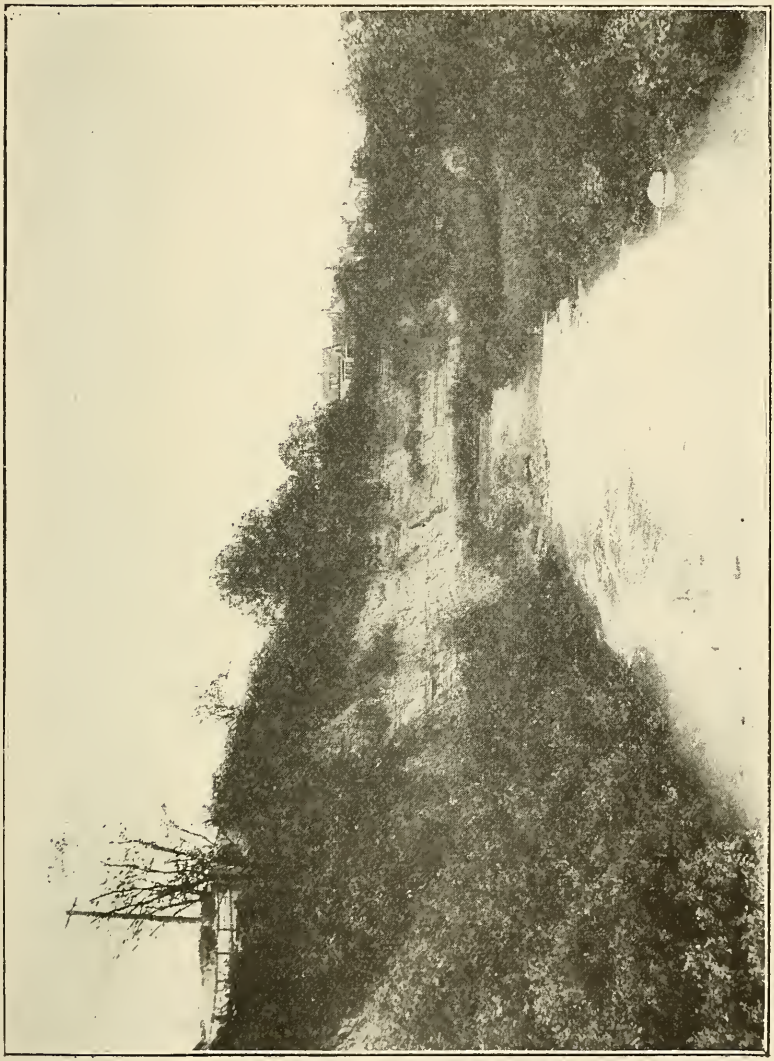

Fig. 2.
An early stage in plant succession.

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of seepage and slumping is frequent. A large talus quickly collects. This is composed of angular fragments of the limestone, embedded in a matrix of the fine mud produced by the weathering of the shale.

The stream through the gorge has a very high gradient. From Main street to Test's Mills, a distance of about 9,000 feet, the total fall is 47 feet, or about 1 foot in 200. This gradient is not at all uniform throughout the distance. In general the stream consists of a series of alternate ponded stretches and rapids. At some of the fall lines a difference of level of six or eight feet may occur. This condition is produced by a slight dip of the rock strata toward the up-stream end of the gorge. This dip is small, not more than a few inches to the hundred feet. Where a portion of the rock, harder than the surrounding rock or with less shale, comes to the surface, a fall line is produced. Fragments of rock carried down by spring floods accumulate at this point, and the portion of the stream immediately above becomes ponded. Some of these ponds are as much as 1,200 feet in length.

The annual rainfall in this region is about 40 inches. The average flow of the river is about 60 cubic feet per second. A series of measurements of the flow, made January–May, 1907, gave a minimum flow of 56 cu. ft. per second on February 20, and a maximum flood stage of 4,500 cu. ft. per second on March 13. Measurements made in August, 1908, indicated a flow of only 42 cu. ft. per second.

It is a deplorable fact that up to the present time the city of Richmond has seen fit to dispose of its sewage by the primitive method of dumping it directly into the river. Since this sewage flow amounts to 12 to 15 cubic feet per second, or one-fourth the total flow at low water stage, the condition of the river below the sewers may be imagined.

The region selected for study includes the floor and bluffs of the gorge between the Main street bridge and the bridge at Test's Mills, about two miles to the south. A survey by transit and stadia was made and from this a topographic map on a scale of 1 inch to 250 feet was prepared. On this the various data were recorded, and the conditions of the various portions of the area were indicated by tints. Considerable areas of the region have been disturbed by cultivation, building operations, etc., and no attempt to study these areas was made. Photographs to show the more striking features of the region were made whenever possible. The nomenclature used is that of Gray's Manual, 7th edition.

Fig. 3.

A slightly later stage than that shown in Fig. 2. Note shelf plants and texture of rock.

In this study, the various plant associations have been considered as members of a succession, and therefore, in general, transitional. The ultimate stage in this region, *i .e.*, the permanent association, is held to be a very mesophytic forest, dominated by Fagus and Acer saccharum. All other plant associations are held to be transitional stages between a plantless condition and this ultimate forest condition. The position of any given plant association in this succession may be determined accurately only by observation over a long period of time. The successive stages have been worked out carefully in many cases, however, and the usual succession for this region is well known. Two kinds of successions are recognized, namely, biogenic and physiogenic. A biogenic succession may be defined as one influenced only by plant and animal life, and therefore such a succession will occur only where the physiography is static. In physiogenic successions, physiographic changes are the controlling factors. In general we have endeavored to determine two points with regard to each plant association, namely, its place in the succession and whether the controlling factors of that succession at that stage are biogenic or physiogenic. Lists of species given are usually incomplete but as representative as possible.

The walls of the gorge and the ravine branching from it are quite favorable for the study of plant successions in such situations. Within the region studied, almost all stages from the bare plantless cliff to the ultimate mesophytic forest can be found. The stage of development of the vegetation on the walls of the gorge seems to be dependent largely upon the length of time that has elapsed since active erosion by the river ceased. The succession is very rapid for a rock cliff. This is explained by the very unstable nature of the rock, the abundance of shale and the favorable conditions of rainfall and climate. Very often stages that are usually successive occur combined, or telescoped, here. Lichens, which usually form the first vegetation on rock cliffs, are absent. No liverworts or ferns occur. The oaks, which commonly form a stage immediately preceding the ultimate forest, seem to be replaced by elms and black locust. Juniperus is the only conifer found.

The earliest stage of the succession occurs at one point where a cliff occupies the outside of a curve of the stream, and active erosion of its foot is going on. As a result of this condition, the cliff is very steep, even overhanging to a slight extent. The wall is bare of plants, except for algae

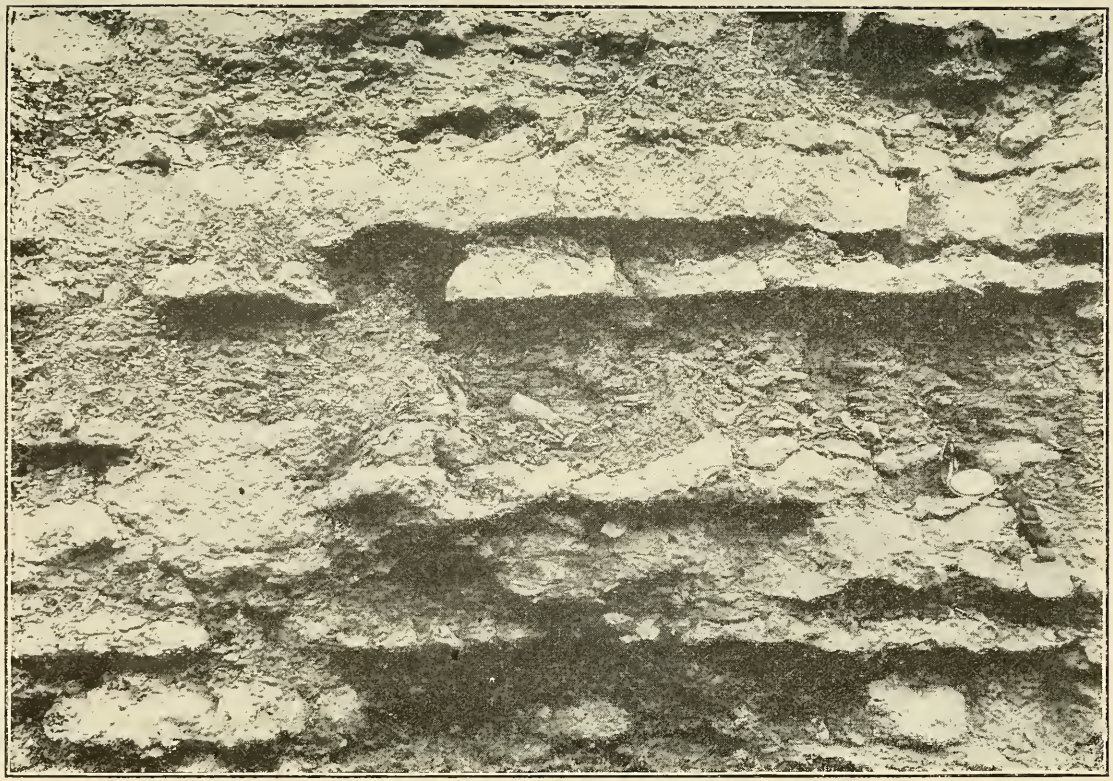

Fig. 4.

Detail of Fig. 3 showing character of rock in gorge. Note alternate layers of limestone and shale.

In places where seepage occurs. No lichens occur, though the rock is more stable than usual, with a smaller proportion of shale. Their absence is not due to smoke, as is sometimes the case, for they occur on trees near by. The rock does not contain bitumen which sometimes prevents their growth, notably on Niagara limestone. It seems probable that the weathering of the rock is too rapid for them to maintain a foothold. A few annuals grow on the talus which has accumulated since the spring floods. A few plants, such as Psedera, Rhus toxicodendron, Vitis and Juniperus virginiana, hang from the top of the cliff. This stage continues as long as active erosion by the stream is maintained.

The second stage is found at a point where the river erosion is not so strong. A considerable talus accumulates at the base of the cliff, and this is not swept away by the spring floods. The wall is not so steep as in the stage just described. It is in this stage that the first real plant associations appear. These pioneer plants occupy narrow shelves produced by the projecting ledges of limestone. Most of the plants are annuals. The following species are typical of such localities:

Ambrosia artemisiæfolia	Melilotus alba
Poa compressa	Allium canadense
Lactuca scariola var. integrata	Dipsacus sylvestris
Nepeta cataria	Aster spp.
Rosa humilis	

After direct action by the river has ceased, the talus accumulates undisturbed. The shale layers change to soil very readily, and this is washed down by the rains. Projecting layers of limestone break off of their own weight. In these various ways, the slope is rapidly reduced. A larger number of plants gain a foothold and the cliff is covered with vegetation. Grasses and annuals are common. Xerophytic mosses appear. This may be called the herb stage. The pioneer plants mentioned above continue through this stage, while the following new species appear:

Equisetum arvense	Melilotus officinalis
Aster novæ-angeliæ	Cornus paniculata
Daucus carota	Verbascum thapsus
Heracleum lanatum	Elymus canadensis

Up to this point, the succession has been almost entirely physiogenic. The plantless stage continues as long as the stream actively erodes the

Fig. 5.

A ponded portion of the stream.

base of the cliff. After this erosion ceases, the plant succession is determined for a time by the slope of the cliff. At first, only shelf plants can gain a foothold. As the slope is reduced, the number of species is increased. After a time, though, when a soil of considerable depth has formed, the succession becomes biogenic. The plants hold the soil, and the reduction of slope proceeds very slowly, if at all, particularly after grasses become prominent. The slope of the gorge wall where it is covered with a mesophytic forest is but little gentler than that of the wall where only bushes occur. From the herb stage to the ultimate mesophytic forest, each plant stage prepares the way for the next in the succession by holding the soil, accumulating humus and furnishing shade.

The herb stage is succeeded by a bush stage. The most prominent species is Rhus canadensis, which often forms large colonies. Cornus paniculata and Salix longifolia are commonly associated with it. Rubus, Ribes, Rhus toxicodendron, Vitis vulpina, Cratægus, Psedera, Ptelea trifoliata and others occur, together with a number of species characteristic of the preceding stage, such as Dipsacus sylvestris, Heracleum lanatum, etc.

This shrub stage is probably very brief and pioneer trees soon appear. Two parallel tree stages appear. Considerable areas are found occupied by Ulmus americana, Celtis occidentalis and Cratægus spp. In other situations similar in all respects, Cersis canadensis, Robinia pseudo-acacia and Prunus americana dominate the vegetation. In both cases, the trees are accompanied by a large number of undergrowth herbs and shrubs, among them the following:

Gleditsia triacanthos	Heracleum lanatum
Juglans nigra	Daucus carota
Cornus paniculata	Taraxacum officinale
Sambucus canadensis	Aster spp.
Ribes cynosbati	Verbascum thapsus
Vitis vulpina	Nepeta cataria
Psedera quinquefolia	Poa compressa
Menispermum canadense	Solanum nigrum
Dipsacus sylvestris	

Following these two parallel stages appears the ultimate stage of the region, the mesophytic forest. This stage occurs only on the east bluff of the gorge, immediately above Test's Mills. That this forest is really

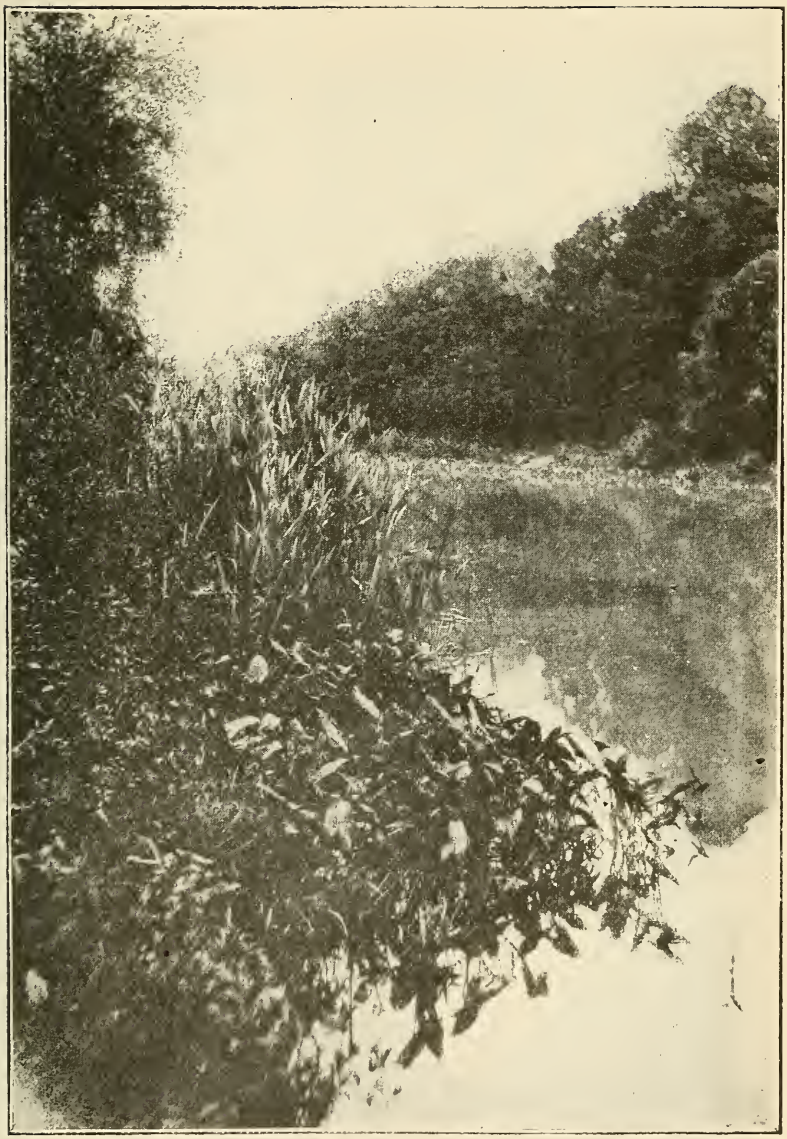

Fig. 6.

Border plants along ponded portion of stream.

mesophytic is shown by the presence of Fagus grandifolia and Acer saccharum, the latter being very abundant. This forest is rather open yand this probably accounts for the absence of all ferns. Polypodium is found in similar locations in this region, however. Mosses are abundant on the ground and on fallen logs. The only liverwort is Porella, occurring abundantly on tree trunks near the ground.

In order to establish the fact that the forest represents the ultimate stage of the succession for this region, a primeval mesophytic forest near Williamsburg, Ind., about ten miles distant, was studied and a list of the species found there is given below. On this list, those species marked by an asterisk occurred also in the forest on the east bluff of the gorge at Test's Mills. A study of the list will lead to the conclusion that the ultimate stage of the succession has been reached here:

*Carpinus caroliniana
*Fraxinus americana
*Fagus grandifolia
*Aesculus glabra
*Ostrya virginiana
*Cornus florida
*Acer saccharum
*Carya cordiformis
*Ulmus racemosa
*Asimina triloba
*Morus rubra
*Smilax hispida
*Psedera quinquefolia
*Ribes cynosbati
*Juniperus communis
*Vitis vulpina
*Rosa setigera
Benzoin æstivale
*Rhus toxicodendron
Celastrus scandens
*Menispermum canadense
*Viburnum prunifolium
*Sambucus canadensis
Mitchella repens
*Carya ovata
*Ulmus americana
*Ulmus fulva
*Tilia americana
*Quercus alba
*Fraxinus quadrangulata
*Celtis occidentalis
*Quercus rubra
Aralia nudicaulis
*Urtica gracilis
Polygonum virginianum
*Bidens frondosa
Monotropa uniflora
Epifagus virginiana
Smilacina racemosa
Boehmeria cylindrica
*Aristolochis serpentaria
Sanguinaria canadensis
*Solanum nigrum
Polygonatum commutatum
Cryptotænia canadensis
Actæa spicata
Viola pubescens
Monarda fistulosa

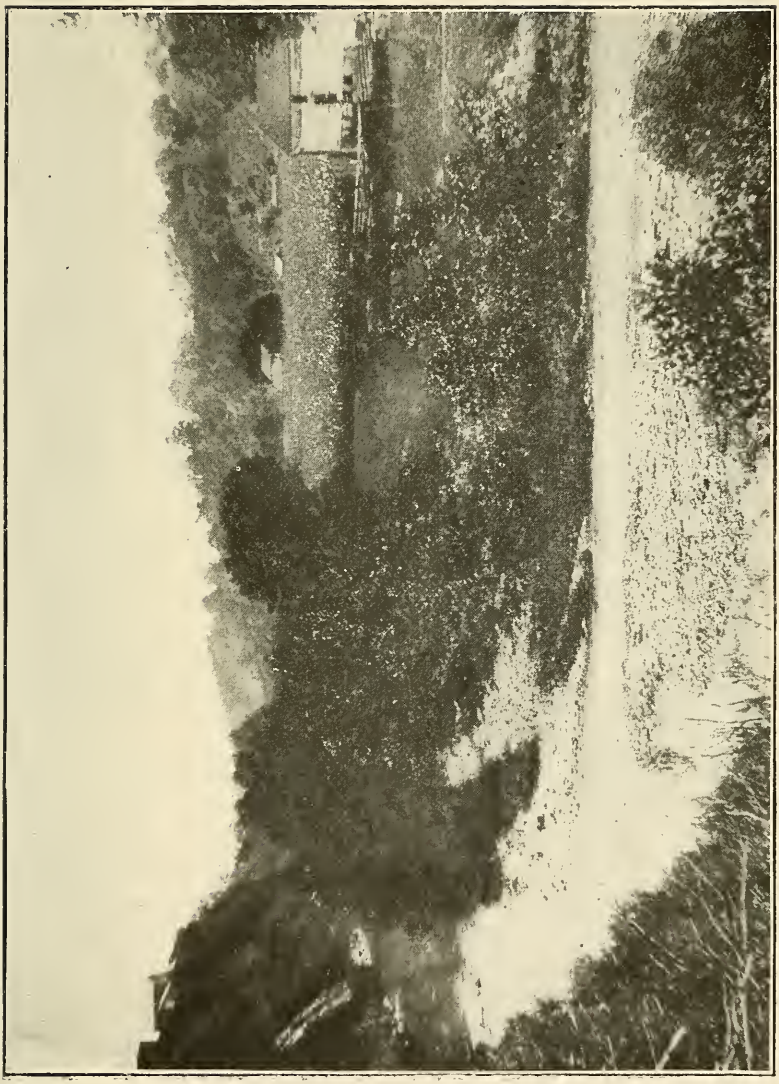

Fig. 7.

A Xerophytic Floodplain.

Hydrangea arborescens	Hepatica acutiloba
*Eupatorium urticæfolium	Arisæma triphyllum
*Impatiens biflora	Botrychium virginianum
Impatiens pallida	Botrychium ternatum
*Galium spp.	Adiantum pedatum
*Viola cucullata	Polystichum acrostichoides
Aralia racemosa	Asplenium augustifolium

In addition to the species indicated by asterisks, Quercus prinus and Sedum ternatum are prominent members of the vegetation of this stage of the bluffs.

Several narrow terraces occur along the sides of the gorge at various points. They vary in width from a few feet to as much as 200 feet, and one of these, on the east side of the river near the bridge at Test's Mills, is about half a mile in length. The origin of these was not investigated.

Rejuvenescence, that is, a return to pioneer conditions, may occur at any stage of the succession, if erosion of the base of the cliff is resumed by the river. In this case, the undercutting by the stream produces slumping, and the bare rock wall is soon exposed. This condition occurs at the foot of the east bluff, just below the small islands at the lower fall line. At this point the bluff had become mesophytic before erosion of the foot began again. We have here at the present time an extremely xerophytic bare rock face bordering directly upon a mesophytic forest. This xerophytic condition will continue as long as the stream erosion continues, and its area may even increase. When erosion ceases, the succession will begin again, and progress through the stages just described.

The ravines entering the gorge are small and comparatively few in number. The fact that the gorge is relatively young explains this in part. The smallness of the area draining into the gorge at this point is probably the principal factor, however. Clear Creek parallels the river on the west, and the divide between the two streams is less than half a mile west of the river. On the east, another small stream parallels the gorge at an even less distance. Accordingly the drainage of the area immediately around the gorge is largely accomplished by parallel streams which enter the river farther down. With two exceptions, the ravines are less than 200 yards in length, and are accordingly very steep. These two ravines have permanent streams, fed by springs. In the others, the rocks drip with seepage, but streams run through them only after rains.

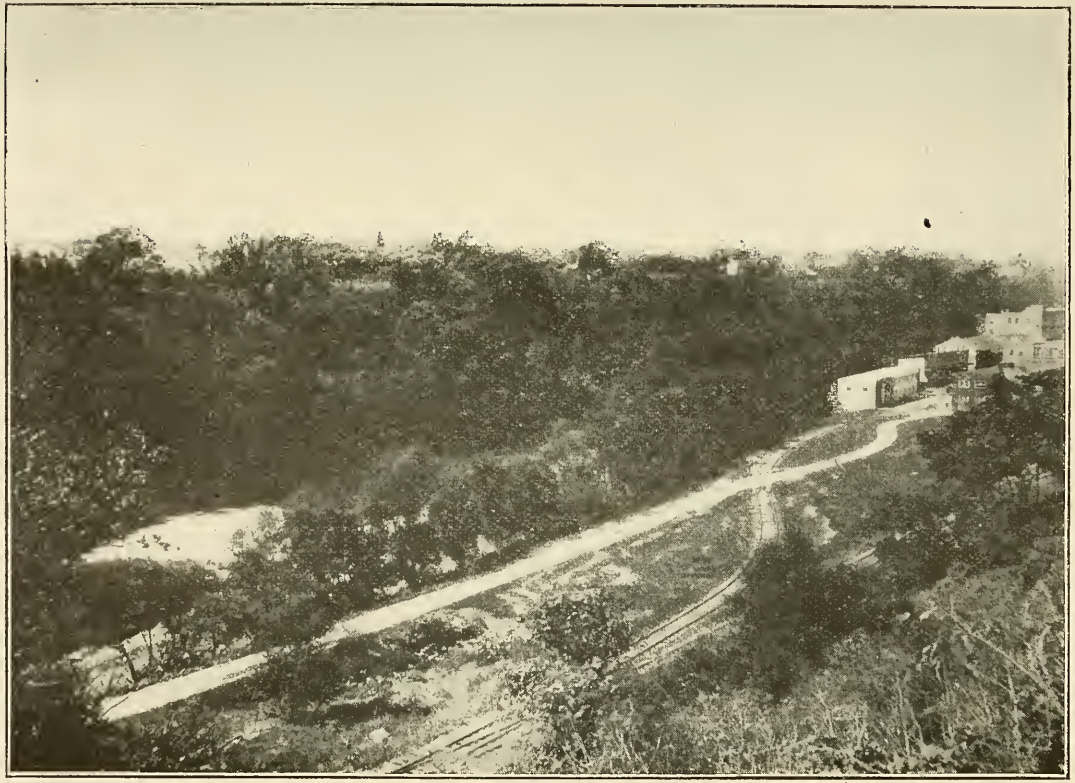

Fig. 8.

View across Gorge. Note nearly mesophytic forest on opposite bluff and border of Salix nigra.

All stages from young ravines, with conditions extremely xerophytic up to mature ravines with mesophytic vegetation are found.

The first stage of one of these ravines is merely a shallow groove down the side of the bluff, floored by the bare bedrock and partially choked by rock fragments. The debris accumulates as a cone at the foot. In this stage, a ravine is extremely xerophytic. Few if any plants grow within them, though a few appear upon the talus at the foot. The plants which do appear are the same as the pioneer plants on a cliff face.

The position of such a ravine seems to be determined almost entirely by the surface drainage outside the gorge. Wherever the topography of the surface outside the gorge causes the flood water to be discharged down the bluff, a ravine will be formed. Cleavage planes, which commonly determine the location of ravines in more massive rock, are absent. Seepage lines which often determine ravines in clay bluffs probably have little effect here, for they often occur on cliff faces where no tendency to ravine formation is evident. The rapidity with which a ravine will grow is of course dependent upon the water supply.

Older ravines are generally not regular in gradient, but become very precipitous in some parts, on account of the occurrence of occasional harder layers of limestone. This produces vertical faces from a few inches to six or eight feet in height, and these are usually wet with seepage or run-off from above. These ravines are usually quite deep and well shaded. Vertical faces of the kind described are commonly covered with Cladophora and Vaucheria. Where the water is contaminated by sewage, Oscillatoria replaces these. Mosses grow luxuriantly in these situations, but no liverworts grow anywhere in these ravines, with the single exception of Porella, which is common in mesophytic situations throughout the region. The absence of liverworts is difficult to account for, in view of the hydromesophytic conditions which prevail in such situations. Fimbriaria and Fegatella were found in abundance on damp rock shelves near Thistlethuaite's Falls, north of Richmond. Aneura and Blasia were found on clay in the same region. Marchantia occurs on rocks in similar localities near this point.

Why mosses should be so abundant and liverworts entirely absent in these ravines is difficult to explain. The finding of several genera of liverworts on similar rock shows that their absence is not due to the chemical nature of the rock. The older parts of the Aneura found on clay were stiff

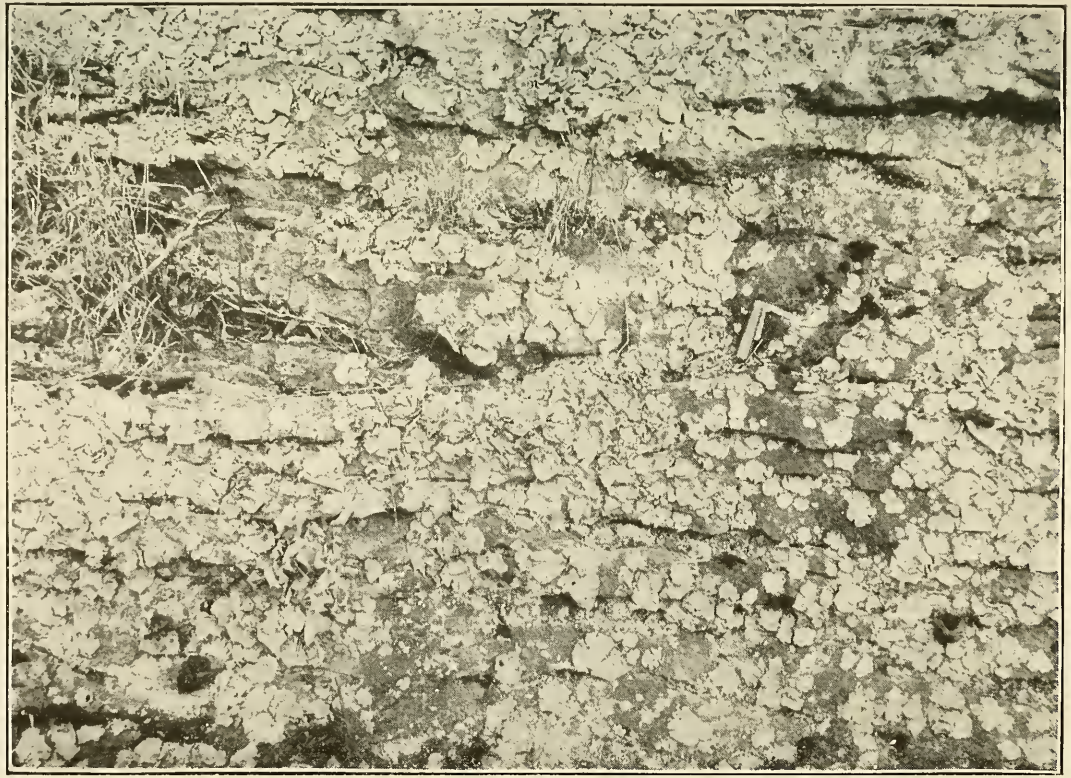

Fig. 9.

Niagara limestone at Elkhorn Falls. Compare character of rock and growth of lichens and mosses with that shown in Fig. 4

with incrustations of calcium carbonate from the seepage water. It is probable that the disintegration of the rock from weathering and stream erosion combined is too rapid to permit the liverworts to maintain a foothold.

The succession from the xerophytic first stage to the ultimate mesophytic stage is very rapid, more so than that of the bluffs. The narrowness of the ravines, the greater amount of shade, and the more constant water supply account for this. The stages passed through are essentially the same as in the case of the bluff.

It is to be noted, however, that until the ultimate mesophytic stage is reached the physiographic factors affect the succession, and that a purely biogenic succession never occurs. In this point the ravine succession differs from that of the bluffs, as already discussed.

That the ultimate stage of the ravine is mesophytic is indicated by the following list of species found in a typical ravine of the region.

Acer saccharum	Vitis vulpina
Quercus prinus	Rhus Toxicodendron
Ostrya virginica	Rubus sp.
Acer negundo	Impatiens biflora
Fagus grandifolia	Impatiens pallida
Fraxinus americana	Ipomœa pandorata
Cercis canadensis	Lobelia syphilitica
Ulmus fulva	Sedum ternatum
Fraxinus quadrangulata	Ambrosia trifida
Gleditsia triacanthos	Viola cucullata
Celtis occidentalis	Eupatorium urticæfolium
Ulmus americana	Sambucus canadensis
Menispermum canadense	Hyrangea arborescens

The successions of the gorge floor are quite as interesting as those of the bluffs and ravines. As already mentioned, the stream is ponded through a large part of the region studied. The conditions which have produced this result have been discussed. In the ponded portions, the water varies in depth from two to five feet, and consequently the current is very slow. As a result of this condition, a typical pond vegetation is found in a number of points within the area. Sagittaria and Typha are characteristic of this condition. Scirpus americanus occurs at a few

points. Submerged and floating plants are absent or unimportant. Below the sewers, Oscillatoria is the only form found. Above them, Cladophora, Hydrodictyon and Potamogeton pectinatus occur. Neither Nymphæa nor Castalia is found, probably because of sewer contamination, together with the rocky character of the bottom.

At a number of points, distinct zonation occurs. The succession may be described as composed of five stages, the first of which is always dominated by Sagittaria. Typha makes up the second stage, and is followed by Bidens lævis, which forms the third stage. Where zonation occurs this Bidens zone is always very definite, and usually extends from the edge of the water back two to ten feet. The fourth stage is represented by a zone dominated by Ambrosia trifida and Eupatorium perfoliatum. Other species are Apocynum cannabinum, Bidens frondosa, Xanthium canadense and Verbena urticæfolia. The final stage is represented by Salix nigra, Platanus occidentalis, Vernonia noveboracensis and Aster novæ-angliæ.

Where all five zones occur, they are very closely crowded together. In one instance all were clearly defined in a space of about fifteen feet. Telescoping of stages is common. In two instances, young willows were found in the midst of the zone of Bidens lævis.

The black willows form a very conspicuous feature of the floor of the gorge. They occur commonly in definite lines which parallel the stream at a distance of ten to fifty feet. A very striking example of this occurs just below the Starr piano factory, on the east side of the river. Other lines of trees of this species occur in similar locations farther down the river.

Hydrophytic flood-plains of the usual kind occur commonly in the floor of the gorge. These may be so low as to be covered by the river at every slight rise, or they may be above the level of the highest flood stage. At the main bend of the river lies a high flood-plain of very considerable size. Low hydrophytic flood-plains lie on both sides of the stream immediately at the Starr piano factory. These are narrow, being only a few feet in width at some places. These show a very characteristic vegetation, as shown by the following typical list of species:

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Salix nigra	Xanthium canadense
salix longifolia	Rudbeckia hirta
Populus deltoides	Bidens frondosa
Salix cordata	Polygonum virginianum
Ambrosia trifida	Helianthus strumosus
Impatiens biflora	Apocynum cannibinum
Impatiens pallida	Lobelia syphilitica
Rumex crispus	Cicuta maculata

Later stages of the succession occur at other points. The succession is rapid, the flood-plains of this kind quickly become mesophytic. The large flood-plain at the bend of the river is thoroughly mesophytic, as shown by the vegetation of the undisturbed portions of it. It is to be noted, however, that the very narrow flood-plains of this type do not become mesophytic quickly, because of their submergence at every flood. By reason of the high gradient of the stream, the current is swift at flood time, and very little material is deposited. In this respect, these areas differ from the usual hydrophytic flood-plains.

A third feature of the gorge floor is the presence of numerous and well-defined flood-plains of a distinctly xerophytic nature. These occur commonly just below the fall lines, in distinction from those of the sides of the ponded stretches. The manner of their formation is easily seen. As already mentioned, the gradient of the stream is high, and at flood times the swift current carries considerable masses of rock and coarse gravel over the lower land immediately below the various fall lines. As a result, these flood-plains below the fall lines and at the curves of the stream are composed of gravel and rock fragments. The islands at the fall line near the lower end of the gorge are subject to the same conditions.

The vegetation of these areas is quite distinctive. On the upstream side, no plants occur for a considerable distance from the water's edge. This corresponds roughly to the bare lower beach of a lake or the ocean, and is the region that is covered by the slight rises of the river during the summer. The pioneer plants are usually Xanthium canadense and Bidens connata. Back of these occur Salix longifolia, Platanus occidentalis and Populus deltoides. Of these, Platanus is the typical species, and from the bluffs the xerophytic flood-plains may be picked out by the

occurrence of this tree, just as the mature hydrophytic flood-plains are indicated by Salix nigra.

Toward the downstream side of these areas, the horizontal succession proceeds rapidly toward mesophytic conditions. Soil accumulates around the trees and the bare rocks and gravel are soon covered. In these locations a rich mesophytic vegetation is found. The following species were noted in such a location:

Salix nigra	Ambrosia artemisiæfolia
Ambrosia trifida	Helianthus strumosus
Bidens frondosa	Eupatorium perfoliatum

It is to be understood that the term "xerophytic" is here used in its broad sense, to indicate that the conditions of plant life are unfavorable in these areas. The extreme thinness of the soil will render water absorption difficult, however plentiful it may be. The range of temperature changes is larger than elsewhere. The trees and other plants are subject to partial submergence at every rise of the river. Perhaps the greatest actual injury comes from floating ice in the winter floods. Sycamores on a xerophytic flood-plain near the bend of the river were more than half cut in two by floating ice, and the upstream side of almost every trunk was dead. The willows commonly show a distinct leaning in the direction of the flow of the river.

We may summarize the results of the investigation as follows: Five distinct plant formations are recognized in the region studied, and each plant association may be referred to one of these five formations: (1) In the rock bluff formation, all stages of the succession from the bare, plantless cliff to a bluff covered by a mesophytic forest, are found within the area under consideration. (2) The same stages of the succession occur in the rock ravine formation. (3) A pond formation occurs at various points of the stream, and the stages of the succession from this condition towards mesophytism may be traced. (4) Definite hydrophytic flood-plains show the usual succession towards mesophytism. (5) Flood-plains of a xerophytic nature occur commonly. The succession to mesophytism in this formation is very rapid. In all of the formations, the trend of the succession is toward a mesophytic forest of the beech-maple type.